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Agricultural Products Supply Chain Coordination: Price and Green Level

Jian Tan

School of Management Science, Guizhou University of Finance and Economics, Guiyang, 550025 China
tanjian123@126.com

Research on the coordination of agricultural products' green supply chain has important practical significance for the development of agriculture. In this paper, the problem of the price and the green level of green supply chain of agricultural products is set up by game theory, three models including centralized decision-making, wholesale price contract and revenue sharing contract are analyzed. Results show that the agricultural products green level and the total income in the centralized decision-making model are the highest. The size of the green level and farmer's profits in the decentralized decision model are determined by the relationship between the parameters of demand responsiveness to green SC's own price, demand responsiveness to enterprise effort level and enterprise effort costs. The enterprise's profits in the wholesale price contract model is higher.

1. Introduction

With the rapid development of the global economy, The change of consumer's demand driven economic development mode, a kind of green supply chain model based on supply chain, considering the resource consumption and environmental impact, came into being. With the development of green, organic and pollution-free, the supply chain of agricultural products becomes an important platform of food quality and safety management. The foundation of the green supply chain implementation is coordination, the contradiction between industrial development and environmental protection is difficult to overcome according to the traditional method of green supply chain management. The theoretical research and practical experience have shown that the establishment of agricultural economy and ecological environment coordinated development and interaction of the symbiotic mechanism is not only possible, but also is a new way of agricultural sustainable development.

In recent years, some scholars have carried out extensive research on the green supply chain. (Barari et al., 2012) established the evolutionary game models for the manufacturers and retailers, and give some suggestions on the environment management. (Ghosh and Shah, 2014) research the two level supply chain consisting of a manufacturer and a retailer, market demand decided jointly by the price and green innovation, and use the two part of the contract to coordinate.(Cheng and Li, 2015) discussed the pricing and greening strategies for the chain members in both centralized and decentralized cases using the Stackelberg game model under a consistent pricing strategy. (Bazan et al., 2015) present two models that consider energy used for production along with the greenhouse gases (GHG) emissions from production and transportation operations in a single-vendor (manufacturer) single-buyer system under a multi-level emission-taxing scheme. (Debabrata and Janat, 2015) explore supply chain coordination issues arising out of green supply chain initiatives and explore the impact of cost sharing contract on the key decisions of supply chain players undertaking green initiatives. (Ashkan, 2015) developed a price competition model of two green and regular supply chains under the influences of government financial intervention, analyzed the effects of government's tariffs on the players' optimal strategies and found that there are specific boundaries for tariffs which guarantee stable competitive market. (Huang et al., 2015) considered a green supply chain with multiple suppliers, a single manufacturer and multiple retailers. A game-theoretic model is established to simultaneously investigate the impacts of the product line design, supplier selection, transportation mode selection and pricing strategies on profits and greenhouse gases emissions. (Yang et al., 2015) formulated

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game mathematical models for product families and supply chains, employed a bi-level, nested genetic algorithm to solve the game.
From the above literatures can be seen, at present, there are few scholars on the agricultural products green supply chain coordination problem for a formal comprehensive discussion. On the basis of the above literatures, we use the game equilibrium model to coordinate the agricultural products green supply chain, and provide a reference for the decision making of green supply chain management.

2. Model description

A green agricultural products supply chain contain an enterprise and a farmer in our models. The enterprise purchase raw agricultural products by price w per unit. After processing agricultural products, the enterprise sell products to the market with price p per unit. In order to produce high quality agricultural products, the joint effort of both sides are needed. The enterprise produce a higher quality of agricultural products through the effort level θ, the farmer should improve the green level g of agricultural products.
Following (Dixit et al., 1979), we assume that the demand information is symmetrically known by both SC members, and the demand function is linear in price, green level and enterprise effort level:

$$d(p,g,\theta)=\phi-\beta p+\lambda g+\gamma\theta \tag{1}$$

Where ϕ is the base market size, β,λ and γ denote the demand responsiveness to green SC's own price, green level and effort level respectively. Products quality effort costs of the enterprise is $\omega\,\theta^2/2$, where ω is the fixed cost parameter of effort.
According to Banker, (Khosla et al., 1998), the cost function of farmer for green SC is given by

$$c(g,x)=(v+\epsilon g)d+\xi\,g^2/2 \tag{2}$$

Thus, the green level selected by the farmer affects total costs in two ways. First, investment of green level improvement program increases fixed production costs $\xi\,g^2/2$, which is increasing and convex in the green level g , and ξ is the fixed cost parameter. Second, the green level also has an impact on the production cost per unit. Specifically, v denotes the variable production cost per unit not including the quality related costs. Given a green level g selected by the farmer, the unit variable cost increases by ϵg, where ϵ>0. We assume λ/β>ϵ, i.e., λ>βϵ.
Let π^F, π^E and π^T denote the profits of the farmer, the manufacturer and the green SC, respectively. We use subscripts C, W and R to denote centralized model, wholesale price contract model and revenue sharing contract, respectively. Superscript * denotes the optimal value.

3. Equilibrium decisions under different contracts

3.1 Centralized decision model equilibrium

Centralized decision model is the vertical integration of enterprise and farmer. The goal of the farmer and the enterprise as a whole is to maximize their overall profits. According to (1) and (2), we can get the profits function for the green SC as follow:

$$\pi_C^T(\theta,p,g)=(p-v-\epsilon g)(\phi-\beta p+\lambda g+\gamma\theta)-\omega\,\theta^2/2-\xi\,g^2/2 \tag{3}$$

The first-order conditions characterizing equilibrium are:

$$\partial\pi_C^T/\partial\theta=p\gamma-v\gamma-g\gamma\epsilon-\theta\omega=0 \tag{4}$$

$$\partial\pi_C^T/\partial p=-2p\beta+v\beta+g\beta\epsilon+\gamma\theta+g\lambda+\phi=0 \tag{5}$$

$$\partial\pi_C^T/\partial g=-\gamma\epsilon\theta-v\lambda-2g\epsilon\lambda+p(\beta\epsilon+\lambda)-g\xi-\epsilon\phi=0 \tag{6}$$

Since$\partial^2\pi_C^T/\partial\theta^2=-\omega<0, \partial^2\pi_C^T/\partial p^2=-2\beta<0$, $\partial^2\pi_C^T/\partial g^2=-2\epsilon\lambda-\xi<0$, note that the Hessian of π_C^T is negative definite for all values of $\theta, p \text{ and } g$ if $-2\beta\omega+\gamma^2\xi+(\beta\epsilon-\lambda)^2\omega<0$.
Solving Eqs.(4)~(6), we obtain the equilibrium price, green level and effort level for the green SC:

$\theta_C^*=\gamma\xi(v\beta-\phi)/(\gamma^2\xi+(\beta^2\epsilon^2+\lambda^2-2\beta(\epsilon\lambda+\xi))\omega)$, $p_C^*=((\beta\epsilon^2-\epsilon\lambda-\xi)\phi\omega+v(\gamma^2\xi+(\lambda^2-\beta(\epsilon\lambda+\xi))\omega))/(\gamma^2\xi+(\beta^2\epsilon^2+\lambda^2-2\beta(\epsilon\lambda+\xi))\omega)$, $g_C^*=-(\beta\epsilon-\lambda)(v\beta-\phi)\omega/(\gamma^2\xi+(\beta^2\epsilon^2+\lambda^2-2\beta(\epsilon\lambda+\xi))\omega)$.

Then we can have:$\pi_C^{T*}=\xi(\phi-v\beta)^2\omega/2(-\gamma^2\xi-(\beta^2\epsilon^2+\lambda^2-2\beta(\epsilon\lambda+\xi))\omega)$,$d_C^{T*}=\beta\xi(v\beta-\phi)\omega/(\gamma^2\xi+(\beta^2\epsilon^2+\lambda^2-2\beta(\epsilon\lambda+\xi))\omega)$.

3.2 Wholesale contract model equilibrium

For the wholesale price contract model, the enterprise purchase agricultural products by price w per unit. After processing agricultural products, the enterprise sell products to the market with price p per unit. We express the profits of the green SC member as follows:

$$\pi_W^E(p,\theta) = (p-w)(\phi - \beta p + \lambda g + \gamma\theta) - \omega\,\theta^2/2 \quad (7)$$

$$\pi_W^F(w,g) = (w - v - \epsilon g)(\phi - \beta p + \lambda g + \gamma\theta) - \xi\, g^2/2 \quad (8)$$

Because of enterprise apply the acquisition to obtain green agricultural products, so the farmer takes the enterprise's reaction into consideration when choosing its strategy. The enterprise's reaction function for a given (w,g) can be derived from the first-order derivative of π_W^E in Eq.(12):

$$\partial\pi_W^E/\partial\theta = p\gamma - w\gamma - \theta\omega = 0 \quad (9)$$

$$\partial\pi_W^E/\partial p = -2p\beta + w\beta + \gamma\theta + g\lambda + \phi = 0 \quad (10)$$

Since $\partial^2\pi_W^E/\partial\theta^2 = -\omega < 0, \partial^2\pi_W^E/\partial p^2 = -2\beta < 0$, note that the Hessian of π_W^F is negative definite for all values of θ and p if $-\gamma^2 + 2\beta\omega > 0$. Solving Eqs.(9)~(10), we can get:

$$\theta_W^* = \gamma(-w\beta + g\lambda + \phi)/(-\gamma^2 + 2\beta\omega) \quad (11)$$

$$p_W^* = (-w\gamma^2 + w\beta\omega + g\lambda\omega + \phi\omega)/(-\gamma^2 + 2\beta\omega) \quad (12)$$

After substituting (11) and (12) into (7), according to its first order derivatives of Eq.(8) with respect to w and g, respectively:

$$\partial\pi_W^F/\partial w = (\beta(v\lambda - w(\beta\epsilon + \lambda) + \epsilon\phi)\omega + g(-\gamma^2\xi + 2\beta(\epsilon\lambda + \xi)\omega))/(\gamma^2 - 2\beta\omega) = 0 \quad (13)$$

$$\partial\pi_W^F/\partial g = \beta(v\beta - 2w\beta + g\beta\epsilon + g\lambda + \phi)\omega/(-\gamma^2 + 2\beta\omega) = 0 \quad (14)$$

We can find the famer optimal wholesale price and green level by solving Eqs.(13) and (14):

$g_W^* = -(\beta\epsilon - \lambda)(v\beta - \phi)\omega/(2\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 2\xi))\omega)$, $w_W^* = \phi(\gamma^2\xi + \beta(\beta\epsilon^2 - \epsilon\lambda - 2\xi)\omega) + v\beta(\gamma^2\xi + (-\beta\epsilon\lambda + \lambda^2 - 2\beta\xi)\omega)/(\beta(2\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 2\xi))\omega))$.

Then we can obtain:

$\theta_W^* = \gamma\xi(v\beta - \phi)/(2\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 2\xi))\omega)$

$p_W^* = (\phi(\gamma^2\xi + \beta(\beta\epsilon^2 - \epsilon\lambda - 3\xi)\omega) + v\beta(\gamma^2\xi + (\lambda^2 - \beta(\epsilon\lambda + \xi))\omega))/\beta(2\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 2\xi))\omega)$

$d_W^* = \beta\xi(v\beta - \phi)\omega/(2\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 2\xi))\omega)$

$\pi_W^{E*} = \xi^2(\phi - v\beta)^2\omega(-\gamma^2 + 2\beta\omega)/\, 2(2\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 2\xi))\omega)^2$

$\pi_W^{F*} = -\xi(\phi - v\beta)^2\omega/2(2\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 2\xi))\omega)$

$\pi_W^{T*} = -\xi(\phi - v\beta)^2\omega(3\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 3\xi))\omega)/2(2\gamma^2\xi + (\beta^2\epsilon^2 + \lambda^2 - 2\beta(\epsilon\lambda + 2\xi))\omega)^2$

3.3 Revenue sharing contract model

Revenue sharing contract is that the farmer sell their products to the manufacturer below the cost, the manufacturer in order to compensate the farmer's losses, return its sales income according to a certain proportion (0<p<1) (agreed upon by both parties) to the farmer, ultimately ensure that the revenue of the two sides level higher than decentralized control condition, achieve the supply chain optimal performance. So we express the profits of the green SC member as follows:

$$\pi_R^E(p,\theta) = (1-\rho)\big((p - v - \epsilon g)(\phi - \beta p + \lambda g + \gamma\theta)\big) - \omega\,\theta^2/2 \quad (15)$$

$$\pi_R^F(\rho,g) = \rho((p - v - \epsilon g)(\phi - \beta p + \lambda g + \gamma\theta)) - \xi\, g^2/2 \quad (16)$$

Because of enterprise apply the acquisition to obtain green agricultural products, so the farmer takes the enterprise's reaction into consideration when chooses its strategy. The enterprise's reaction function for a given (w,g) can be derived from the first-order derivative of π_R^E in Eq.(15):

$$\partial\pi_R^E/\partial\theta = -\gamma(p - v - g\epsilon)(-1+\rho) - \theta\omega = 0 \quad (17)$$

$$\partial\pi_R^E/\partial p = (-1+\rho)(2p\beta - v\beta - g\beta\epsilon - \gamma\theta - g\lambda - \phi) = 0 \quad (18)$$

Since $\partial^2\pi_R^E/\partial\theta^2 = -\omega < 0, \partial^2\pi_R^E/\partial p^2 = 2\beta(-1+\rho) < 0$, note that the Hessian of π_R^F is negative definite for all values of θ and p if $(-1+\rho)(\gamma^2(-1+\rho) + 2\beta\omega) > 0$. Solving Eqs.(17)~(18), we can get:

$$\theta_R^* = \gamma(-1+\rho)(v\beta + g\beta\epsilon - g\lambda - \phi)/(\gamma^2(-1+\rho) + 2\beta\omega) \quad (19)$$

$$p_R^* = (\phi\omega + v(\gamma^2(-1+\rho) + \beta\omega) + g(\gamma^2\epsilon(-1+\rho) + (\beta\epsilon + \lambda)\omega))/\gamma^2(-1+\rho) + 2\beta\omega \quad (20)$$

After substituting (19),(20) into (16), according to its first order derivatives with respect to w and g respectively:

$$\partial\pi_R^F/\partial g = 0 \tag{21}$$

$$\partial\pi_R^F/\partial\rho = 0 \tag{22}$$

We can find optimal Revenue sharing proportion and green level of the famer by solving Eqs.(21) and (22):

$$\rho_R^* = -1 + 2\beta\omega/\gamma^2 \tag{23}$$

Because 0<ρ<1, so $\beta\omega<\gamma^2<2\beta\omega$ should be established.

$$g_R^* = -\beta(\beta\epsilon - \lambda)(v\beta - \phi)\omega^2/(2\gamma^4\xi - 4\beta\gamma^2\xi\omega + \beta(-\beta\epsilon + \lambda)^2\omega^2) \tag{24}$$

Then we can obtain:θ_R^* , p_R^*, d_R^* ,π_R^{E*},π_R^{F*} ,π_R^{T*}.

4. Results discussion

4.1 Green level

Proposition 1: When $\gamma < \sqrt{\beta\omega}$, $g_T^* > g_W^* > g_R^*$;when $\gamma > \sqrt{\beta\omega}$, $g_T^* > g_R^* > g_W^*$.

Proof: Omitted.

Proposition 1 shows that the green level of agricultural products is the highest in the centralized decision model. In the decentralized decision model, the green level is determined by the relationship between γ^2 and $\beta\omega$. When $\gamma^2 < \beta\omega$, the green level of wholesale contract model is higher than the green level of revenue sharing contract model, while the result is the opposite when$\gamma^2 > \beta\omega$. Simulation figure 1 confirms this(ϕ=10000).

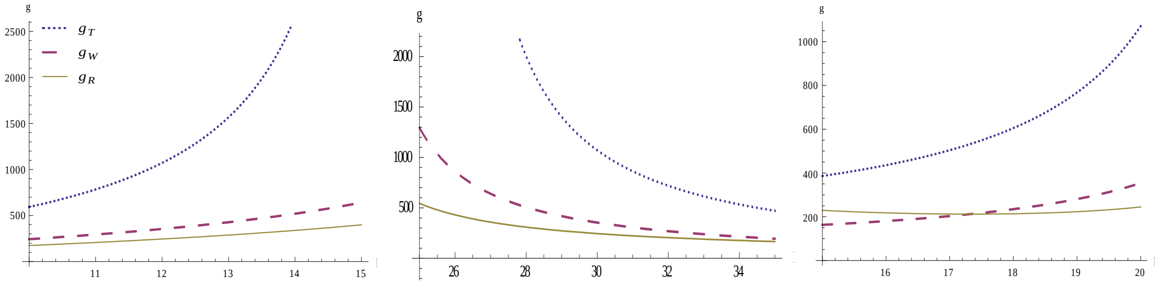

Figure 1: Green level vary with parameter λ,β and γ(β=30,v=20,ϵ=0.1,γ=20,ξ=8,ω=10)

Proposition 2: $dg_T^*/d\lambda > 0, dg_W^*/d\lambda > 0, dg_R^*/d\lambda > 0$; $dg_T^*/d\beta < 0, dg_W^*/d\beta < 0, dg_R^*/d\beta < 0$;
$dg_T^*/d\gamma > 0, dg_W^*/d\gamma > 0, dg_R^*/d\gamma > 0$ if $\gamma > \sqrt{\beta\omega}$;$dg_T^*/d\gamma > 0, dg_W^*/d\gamma > 0, dg_R^*/d\gamma < 0$ if $\gamma < \sqrt{\beta\omega}$.

Proof: Omitted.

From proposition 2 we can know that, with the increase of the demand responsiveness to green SC's green level, the green level increases gradually, which means that consumer are more sensitive to green level, then the higher of product green level. With the increase of the demand responsiveness to green SC's product price, the green level decreases gradually. It denotes that the higher the consumer price sensitivity, the product of the green level will be reduced. Simulation figure 1 confirms the proposition.

4.2 Quality effort level

Proposition 3: $\theta_T>\theta_W>\theta_R$.

Proof: Omitted.

Proposition 4: $\boldsymbol{d\theta_T^*/d\beta < 0, d\theta_W^*/d\beta < 0, d\theta_R^*/d\beta < 0}$;
$\boldsymbol{d\theta_T^*/d\gamma > 0, d\theta_W^*/d\gamma > 0, d\theta_R^*/d\gamma > 0}$;
$\boldsymbol{d\theta_T^*/d\lambda > 0, d\theta_W^*/d\lambda > 0, d\theta_R^*/d\lambda > 0}$, if $\boldsymbol{\gamma > \sqrt{\beta\omega}}$;
$\boldsymbol{d\theta_T^*/d\lambda > 0, d\theta_W^*/d\lambda > 0, d\theta_R^*/d\lambda < 0}$, if $\boldsymbol{\gamma < \sqrt{\beta\omega}}$.

Proof: Omitted.

These two propositions indicate that the manufacturer's effort to improve the level of the green level, is largest in the concentration decision model, while it is the smallest in the revenue sharing contract model. With the increase of the demand responsiveness to green SC's product price, the manufacturer's effort decreases gradually. With the increase of the demand responsiveness to green SC's effort level, the manufacturer's effort increases gradually. Simulation figure 2 confirms the propositions.

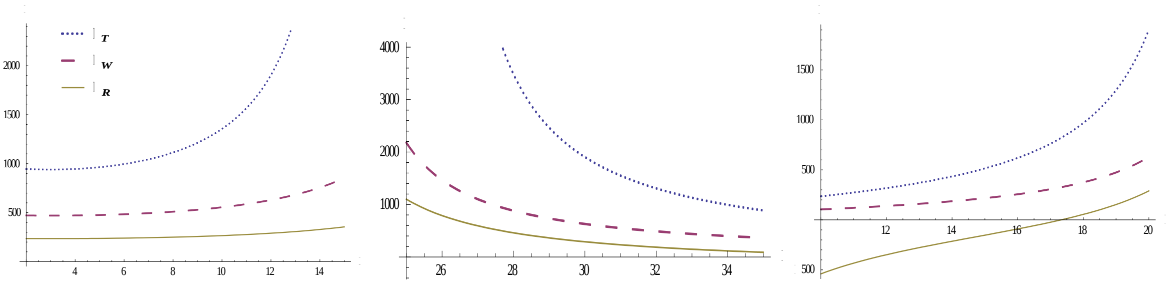

Figure 2: Quality effort level vary with parameter λ,β and γ(β=30,v=20,ϵ=0.1,γ=20,ξ=8,ω=10)

4.3 Profits

Proposition 5: $\pi_T^{T*} > \pi_W^{T*} > \pi_R^{T*}; d\pi_T^{T*}/d\lambda > 0, d\pi_W^{T*}/d\lambda > 0, d\pi_R^{T*}/d\lambda > 0; d\pi_T^{T*}/d\beta < 0, d\pi_W^{T*}/d\beta < 0, d\pi_R^{T*}/d\beta < 0; d\pi_T^{T*}/d\gamma > 0, d\pi_W^{T*}/d\gamma > 0, d\pi_R^{T*}/d\gamma > 0.$

Proof: Omitted.

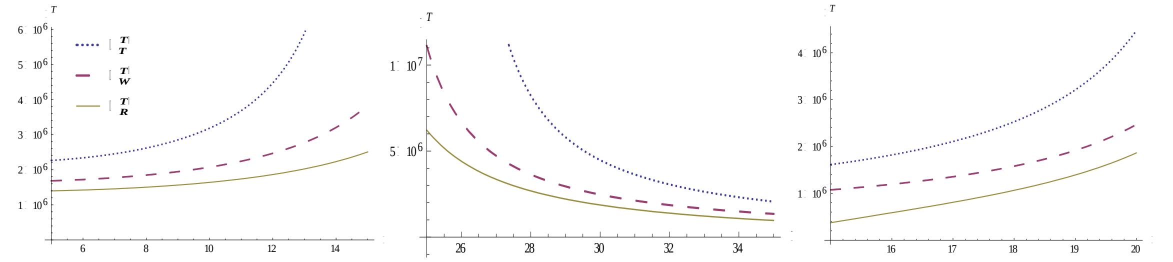

Figure 3: Total profits vary with parameter λ,β and γ(β=30,v=20,ϵ=0.1,γ=20,ξ=8,ω=10)

Proposition 5 shows that the total profits is the highest in the centralized decision model. In the decentralized decision model, the total profits of wholesale contract model is higher than the total profits of revenue sharing contract model. The increase of λ and γ are helpful to the increase of the total profit. Simulation figure 3 verifies these conclusions.

Proposition 6: $\pi_W^{F*} < \pi_R^{F*}$, if $\gamma < \sqrt{\beta\omega}$;

$\pi_W^{F*} > \pi_R^{F*}$, if $\gamma > \sqrt{\beta\omega}$;

$d\pi_W^{F*}/d\lambda > 0, d\pi_R^{F*}/d\lambda > 0$;

$d\pi_W^{F*}/d\beta < 0, d\pi_R^{F*}/d\beta < 0$;

$d\pi_W^{F*}/d\gamma > 0, d\pi_R^{F*}/d\gamma < 0$, if $\gamma < \sqrt{\beta\omega}$; $d\pi_R^{F*}/d\gamma > 0$, if $\gamma > \sqrt{\beta\omega}$.

Proof: Omitted.

As can be seen from proposition 6, for the farmer, the use of which kind of contract depends on the relationship between γ and $\sqrt{\beta\omega}$. The increase of λ is beneficial to the increase of farmer's profits, while the increase of β is not conducive to the increase of farmer's profits. In the wholesale price contract model, γ increasing is beneficial to the improvement of farmer's profits; in the revenue sharing contract, when $\gamma < \sqrt{\beta\omega}$, γ increased which leads to the reduction of farmer's profits. When $\gamma > \sqrt{\beta\omega}$, farmer's profits increased with the increasing of γ. Figure 4 verifies the above conclusions.

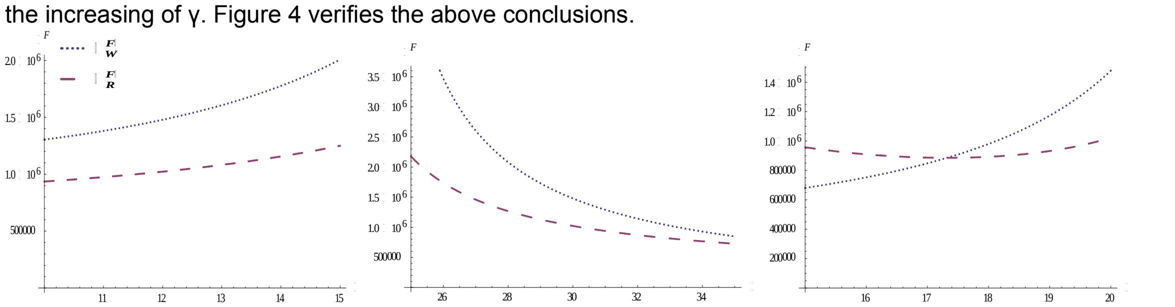

Figure 4: Farmer's profits vary with parameter λ, β and γ (β=30, v=20, ϵ=0.1, γ=20, ξ=8, ω=10)

Proposition 7: $\pi_W^{E*} > \pi_R^{E*}; d\pi_W^{E*}/d\lambda > 0, d\pi_R^{E*}/d\lambda > 0; d\pi_W^{E*}/d\beta < 0, d\pi_R^{E*}/d\beta < 0; d\pi_W^{E*}/d\gamma > 0, d\pi_R^{E*}/d\gamma > 0.$

Proof: Omitted.

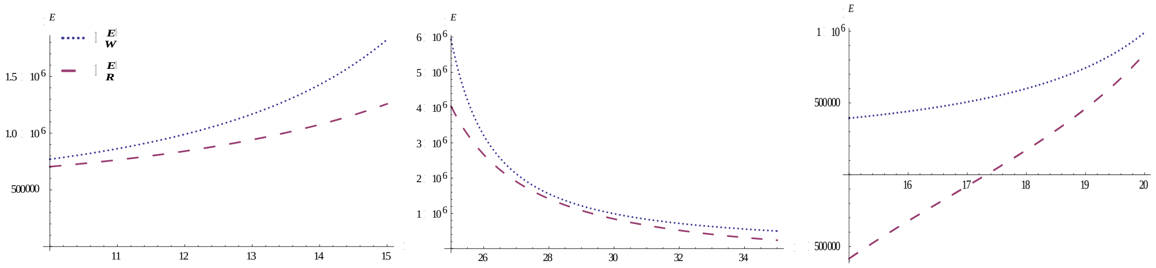

Figure 5: Enterprise's profits vary with parameter λ,β and γ(β=30,v=20,ϵ=0.1,γ=20,ξ=8,ω=10)

As can be seen from proposition 7, the enterprise's profits in the wholesale price contract model is higher. The increase of λ is beneficial to the increase of enterprise's profits, the increase of β is not conducive to the increase of enterprise's profits. γ increasing is beneficial to the improvement of enterprise's profits. Figure 5 verifies the above conclusions.

5. Conclusion

In this paper, the problem of the price and the green level of green supply chain of agricultural products is set up by the game theory, the three models of centralized decision-making, wholesale price contract and revenue sharing contract are analyzed. Results show that the agricultural products green level and the total income in the centralized decision-making model are the highest. The size of the green level and farmer's profits in the decentralized decision model are determined by the relationship between the parameters of demand responsiveness to green SC's own price, demand responsiveness to enterprise effort level and enterprise effort costs. The enterprise's profits in the wholesale price contract model is higher.

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